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FOURTH QUARTERLY REPORT
HEAT PIPE THERMIONIC
CONVERTER DEVELOPMENT

Contract No. 951465

1 May to 17 July 1967

Prepared for
The Jet Propulsion Laboratory
Pasadena, California

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FOURTH QUARTERLY REPORT HEAT PIPE THERMIONIC CONVERTER DEVELOPMENT

1. Introduction

This document constitutes the Fourth Quarterly Report of the work being performed under Thermo Electron's Contract No. 951465 with the Jet Propulsion Laboratory.

This report covers progress for the period 1 May to 17 July 1967. During this period model T/E-3 has been fabricated and tested. The model is a thermionic converter with a heat pipe structure, and it has successfully met all the design requirements. It has been operated for 400 hours at full power, and it has been cycled in rapid start-up and cool-down sequences for 12 times without failure.



2. Fabrication of T/E-3

As mentioned in the Monthly Report No. 8, the fabrication of model T/E-3 was undertaken using the radiator and collector heat pipe structure used as a back-up for T/E-2. To use this structure it was necessary to disassemble it in order to correct a faulty positioning of the capillary structure. The disassembly was carried out by grinding off the end cap of the heat pipe and pulling out the tight-fitting capillary structure. A new capillary was inserted, and a new end cap was welded in place. The capillary was made using a mandrel of slightly reduced diameter to ensure a loose fitting of the capillary into the heat pipe. After the end cap was welded in place, it was noticed that the heat of welding had caused a very minor reaction of the casting with the niobium in the vicinity of the weld. This reaction is known to embrittle the niobium, and it was therefore decided to carefully check the worthiness of the welded assembly. It was placed in a vacuum furnace and cycled abruptly four times to 900°C for a total of 18 hours, and the structure was leak-tight after test. It was then accepted for assembly of T/E-3.

The assembly proceeded normally, and it included mounting a rhemium emitter structure in order to make possible the fabrication of a complete converter heat pipe.

After complete fabrication, the heat pipe was outgassed overnight with a resistance heater at 500°C while maintaining the sodium reservoir at 350°C for 36 hours. The sodium was then transferred to the heat pipe, and the heat pipe fill tube was pinched off by electron bombardment.

To proceed with the cesium charge, a cesium tubulation was fuse-brazed to the cesium tube, and a leak was discovered in the wall of the tantalum tube. To solve this difficulty, a niobium tube was welded



over the tantalum tube so as to cover the leak, and this approach was successful. The converter was then outgassed with a molybdenum foil around the radiator to maintain a high collector outgassing temperature. The outgassing time was 15 hours at an emitter temperature of 1550°C and a collector heat pipe temperature of 700°C . Cesium distillation was then carried out by capsule heating to 200°C for four hours. The completed assembly is shown in Figure 1.

7807

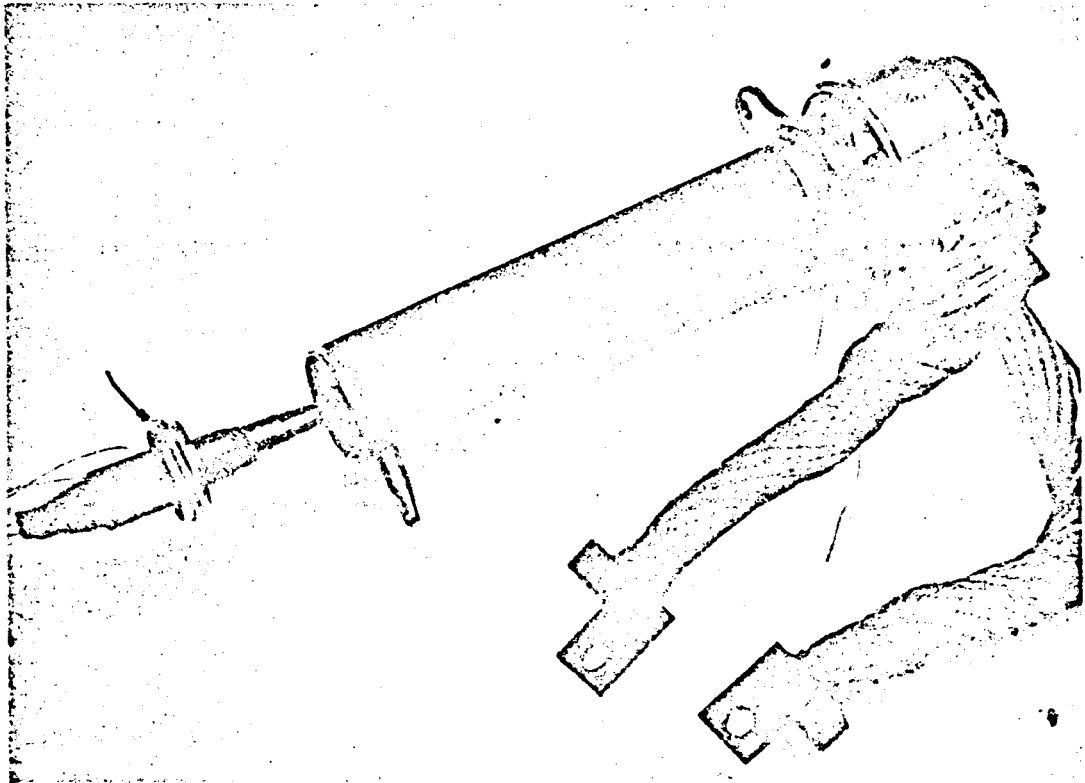


Figure 1



3. Test of T/E-3

Converter T/E-3 was instrumented with voltage taps on the output leads at the point of attachment to the converter, two thermocouples on the cesium reservoir, and two spot-welded thermocouples on the support flange, close to the heat pipe, so as to afford a measurement of heat pipe temperature.

Testing of T/E-3 consisted of five runs. In the first run the steady-state output characteristics were measured at output voltages of 1.2, 1.0, 0.8 and 0.6 volts at emitter hohlraum temperatures of 1600, 1700 and 1800°C. The outputs observed were lower than observed in the T-200 converter series, most likely because of the use of a niobium collector, which has a notorious reputation for poor performance. Also, the collector surface was not given the fine surface finishing used for the T-200 converters, and therefore the interelectrode spacing achieved was probably quite non-uniform. Typically the output voltage of converter T/E-3 was 0.2 volt lower than that of T-206 at any selected output current and emitter temperature.

In the second run, the output characteristics at an emitter surface temperature of 2000°K were obtained under dynamic testing, and these are presented in Figure 2. The characteristics, when compared with those obtained with converter T-206, confirm a voltage shift of 0.2 volt in the optimum curve, and they also reveal that T/E-3 optimized at cesium reservoir temperatures about 10 degrees higher than T-206. The higher optimum reservoir temperature is consistent with the assumption that the lower performance is due to the use of a poor collector material.



7808

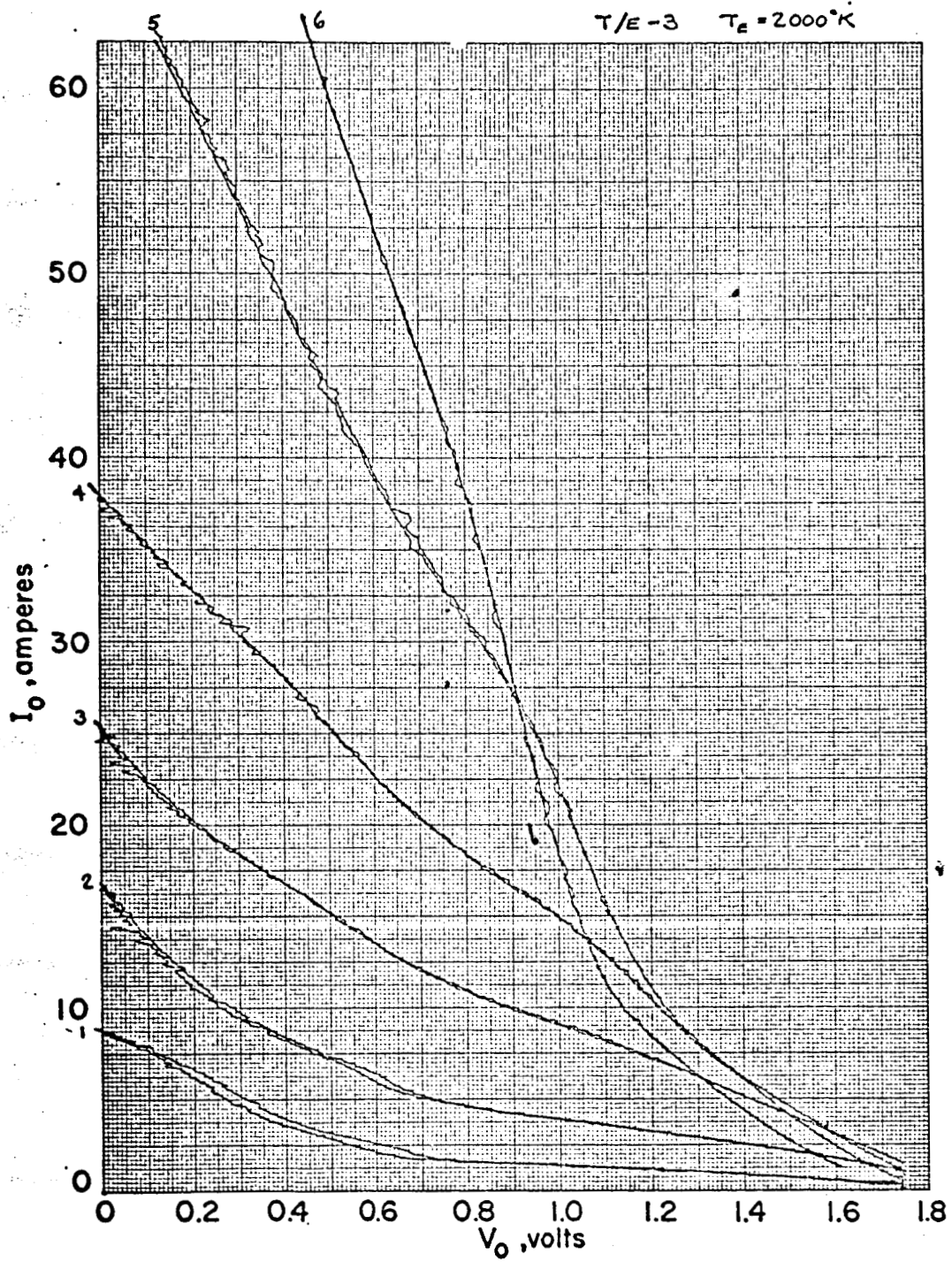


Figure 2



In the third run, the converter was run continuously at a hohlraum temperature of 1700°C with a load adjusted for an output of 0.6 volt at 52 amperes. The steady-state heat pipe temperature was 720°C . The converter operated at this setting for 200 hours.

In the fourth run the converter was thermally cycled abruptly between near-room-temperature and operating temperature. The power input for an output of 52 amperes at 1700°C was turned on and off instantaneously for 12 thermal cycles. Figure 3 shows a typical temperature recording which was obtained during the eighth cycle. Also, in the interval between the fifth and sixth cycles, the converter was run for an additional 200 hours at steady-state and high current output.

The fifth run was conducted to determine the effect of the voltage tap location on the performance measured. The voltage tap on the emitter terminal was shifted to a more advantageous location, as illustrated in data sheet No. 7, but no effect was observed.

7810

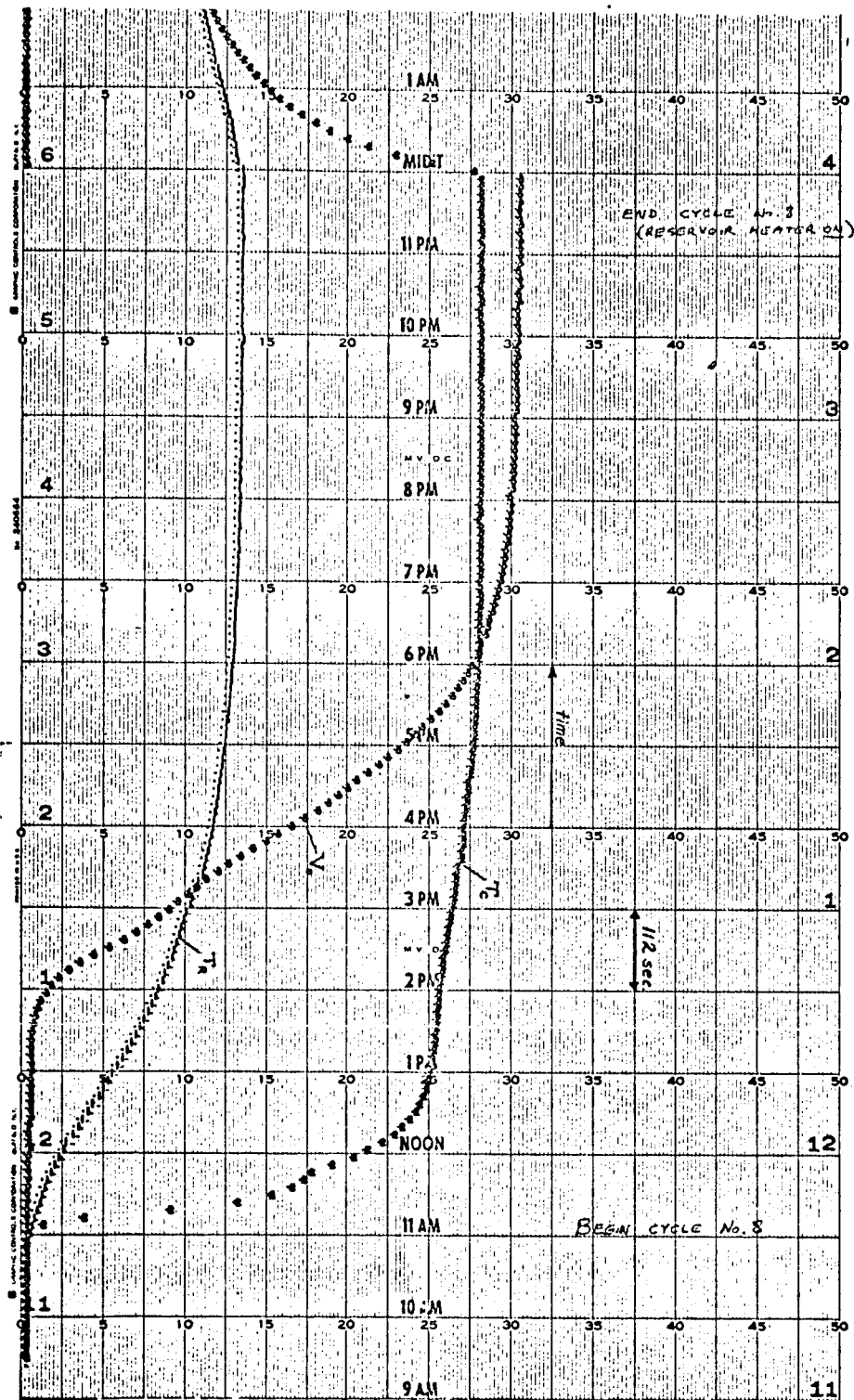


Figure 3



4. Conclusions

The heat pipe model T/E-3 demonstrated for the first time the operation of a SET-type converter with a collector radiator heat pipe. All JPL requirements were met without failure of the model.

One of the most interesting results is presented in Figure 4, which compares the dynamic and static performance obtained with the model. With the previous converters, this comparison always shows agreement at low output currents, but at higher currents the static data falls far below the dynamic data because the collector-radiator structure cannot handle the larger heat transfer, and the collector overheats. The heat pipe of T/E-3 was designed to avoid this limitation, and Figure 4 shows that the static data remains in agreement with the dynamic data at all values of output current.

During the next quarter, the final model T/E-4 will be fabricated and tested. The model will have a larger heat pipe diameter in order to provide optimized operation at output currents as high as 80 amperes.

7809

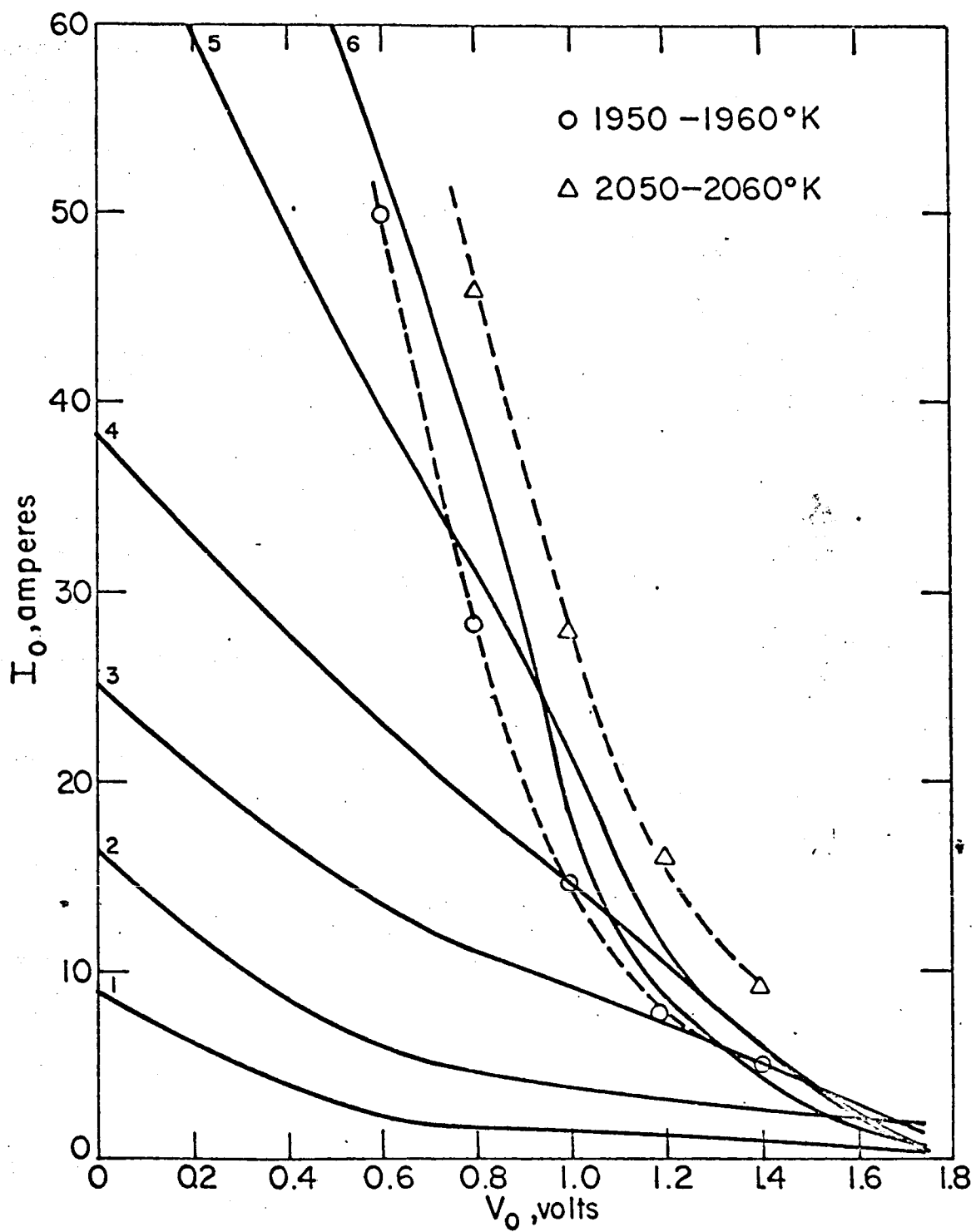


Figure 4



Converter No. T/E-3

Run No. 1

Observer P. Brosenn

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		6-22-67	6-22	6-22	6-22	6-23	6-23	6-23	6-23	6-23	
Time		15:43	16:10	16:37	17:15	16:10	16:28	16:49	17:15	17:38	
Elapsed Time, Hours		1.3	1.7	2.2	2.8	4.0	4.3	4.7	5.3	5.5	
T_0 , °C		1585	1585	1585	1585	1682	1682	1682	1682	1682	
T_0 Corrected, °C	(3)	1590	1590	1590	1590	1688	1688	1688	1688	1688	
$\Delta T_{\text{Bell Jar}}$, °C	(1)	10	10	10	10	12	12	12	12	12	
T_H , °C		1600	1600	1600	1600	1700	1700	1700	1700	1700	
ΔT_E , °C		11	11	12	18	11	12	14	17	22	
T_E , °K		1862	1862	1861	1853	1962	1961	1959	1956	1951	
V_0 , volts	(2)	1.195	1.008	.800	.601	1.400	1.190	0.997	0.800	0.598	
I_0 , amps		3.9	5.3	10.9	30.7	4.9	7.6	14.6	28.4	49.9	
P_0 , watts											
I-V Trace No.					(5)						
T_R	mv	12.6	12.9	13.2	14.3	13.2	13.3	13.7	14.5	15.4	
	°C	309	317	324	350	324	326	336	355	376	
	°K	582	590	597	623	597	599	609	628	649	
T_C Heat Pipe	mv	16.3	22.9	23.9	26.9	24.4	24.9	26.0	27.9	30.1	
	°C	398	553	576	647	588	600	626	671	723	
	°K	671	826	849	920	861	873	899	944	996	
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
T_{Radiator}	mv										
	°C										
V_{eb} , volts		986	985	983	975	983	981	978	972	964	
I_{eb} , mA		197.5	201.0	214.9	277.7	240.1	248.1	271.5	312.9	381.4	
E_{Filament} , volts		4.8	4.8	4.8	4.9	4.6	4.7	4.8	5.0	5.2	
I_{Filament} , amps		22	22	22	23	21	22	22	23	24	
$I_{\text{Coll. Heater}}$, amps		—	—	—	—	—	—	—	—	—	
$I_{\text{Res. Heater}}$, amps		2.11	2.19	2.19	2.29	2.14	2.11	2.20	2.24	2.17	
Vacuum, 10^{-6} mm Hg		5.2	4.4	4.1	4.5	3.0	3.1	3.2	4.0	5.8	
Measured Efficiency, %											

NOTES: (1) $\Delta T = 10 + 0.25 I$
 (2) VOLTAGE TAPS AT LEAD ATTACHMENT POINTS
 (3) PYROMETER CORRECTIONS (CALIB. 5-17) +5°C @ 1600°C, +6°C @ 1700°C
 (4) BELL JAR CORRECTIONS +10°C @ 1600°C, +12°C @ 1700°C.
 (5) SHUT DOWN OVERNIGHT



Converter No. T/E-3

Run No. 1 & 2

Observer P. Brosemer

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		6-26	6-26	6-26	6-26	6-26	6-26	6-26	6-26	6-26	6-26
Time (1)		15:20	15:30	15:40	16:01	16:25	17:22	17:32	17:38	17:44	17:52
Elapsed Time, Hours		11.6	11.8	12.0	12.3	12.7	13.6	13.8	13.9	14.0	14.2
T_O , °C		1779	—	—	—	1682	1720	1721	1722	1723	1725
T_O Corrected, °C		1786	—	—	—	1688	1726	1727	1728	1729	1731
$\Delta T_{Bell Jar}$, °C		14	—	—	—	12	12	12	12	12	12
T_H , °C		1800	—	—	—	1700	1738	1739	1740	1741	1743
ΔT_E , °C		12	14	17	22	22	11	12	13	14	16
T_E , °K		2061	2059	2056	2051	1951	2000	2000	2000	2000	2000
V_O , volts		1.400	1.200	1.000	0.800	0.600	—	—	—	—	—
I_O , amps		9.2	15.9	28.0	46.1	50.4	4	8	11	18	25
P_O , watts						(2)					
I-V Trace No.							1	2	3	4	5
T_R	mv	13.8	14.4	14.9	15.5	15.3	11.0	11.8	12.6	13.4	14.3
	°C	338	353	364	379	374	271	290	309	329	350
	°K	611	626	637	652	647	544	563	582	602	623
T_C	mv	26.6	27.5	28.9	30.9	30.2	24.2	24.9	25.9	26.9	28.6
	°C	640	661	694	742	725	583	600	623	647	687
	°K	913	934	967	1015	998	856	873	896	920	960
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb} , volts		971	968	964	957	962	979	978	975	972	968
I_{eb} , mA		306.9	330.8	370.5	433.0	380.0	235.4	244.0	270.8	290.2	331.7
$E_{Filament}$, volts		5.0	5.0	5.1	5.3	5.2	4.7	4.7	4.8	4.8	5.0
$I_{Filament}$, amps		23	23	23	24	24	22	22	22	22	23
$I_{Coll. Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res. Heater}$, amps		2.21	2.22	2.22	2.26	2.23	0.5	—	1.71	1.85	2.86
Vacuum, 10^{-6} mm Hg		2.8	2.8	3.0	4.8	4.0	2.6	2.6	2.6	2.6	2.6
Measured Efficiency, %											

NOTES: (1) TURNED ON AT 9:30 AM
(2) FILAMENT POWER VERY HIGH. CHOSE NOT TO GO TO 0.6V @ 1800°C
COMPARE WITH DATA POINT SHEET 1 # 9.



Converter No. T/E - 3

Run No. 2 & 3

Observer P. Brosius

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		6-26	6-26	6-27	6-27	6-27	6-28	6-28	6-28	6-29	6-30
Time		17:58	18:10	11:43	13:34	17:30	10:02	12:50	14:46	9:34	9:44
Elapsed Time, Hours		14.3	14.4	32.0	33.9	37.8	54.3	57.1	59.1	77.9	102.0
$T_0, ^\circ\text{C}$		1726	1683	1673	1683	1680	1683	1684	1680	1683	1692
T_0 Corrected, $^\circ\text{C}$		1732	1688	1678	1688	1685	1688	1689	1685	1688	1698
$\Delta T_{\text{Bell Jar}}, ^\circ\text{C}$		12	11	11	11	11	11	11	11	11	11
$T_H, ^\circ\text{C}$		1744	1699	1689	1699	1696	1699	1700	1696	1699	1709
$\Delta T_E, ^\circ\text{C}$		17	23	23	23	23	23	23	23	23	23
$T_E, ^\circ\text{K}$		2000	1949	1939	1949	1946	1949	1950	1946	1949	1959
V_0 , volts		—	0.600	0.588	0.600	0.599	0.598	0.598	0.599	0.601	0.603
I_0 , amps		30	50.9	51.9	51.2	51.6	51.6	51.9	51.3	51.9	52.5
P_0 , watts											
I-V Trace No.		6									
T_R	mv	15.2	15.0	15.3	15.1	15.1	15.3	15.2	15.1	15.0	15.2
	$^\circ\text{C}$	372	367	374	369	369	374	372	369	367	372
	$^\circ\text{K}$	645	640	647	642	642	647	645	642	640	645
T_C	mv	28.7	30.1	29.9	30.0	30.2	30.0	30.0	29.9	29.9	29.9
	$^\circ\text{C}$	690	723	718	721	725	721	721	718	718	718
	$^\circ\text{K}$	963	996	981	994	998	994	994	981	981	981
T_C base inner	mv				760						
	$^\circ\text{C}$										
T_C base outer	mv			(2)							
	$^\circ\text{C}$										
T_{Radiator}	mv										
	$^\circ\text{C}$										
V_{eb} , volts		967	962	961	961	962	959	960	960	961	961
I_{eb} , mA		345.0	382.9	379.9	381.2	380.3	380.4	381.2	380.0	381.4	382.3
E_{Filament} , volts		5.0	5.1	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
I_{Filament} , amps		23	23	23	23	23	23	23	23	23	23
$I_{\text{Coll. Heater}}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{\text{Res. Heater}}$, amps		2.42	2.17	2.17	2.17	2.16	2.17	2.17	2.18	2.18	2.19
Vacuum, 10^{-6} mm Hg		2.8	2.9	2.6	2.5	2.5	2.4	2.4	2.3	2.3	2.3
Measured Efficiency, %											

NOTES: (1) LEFT TO RUN OVERNIGHT
(2) PYROMETER READINGS ON HEAT PIPE, TOP TO BOTTOM. READINGS AFFECTED BY BACKGROUND LIGHTING IN LAB.



Converter No. T/E-3

Run No. 3 & 4

Observer P. Brown

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		7-2	7-5	7-5	7-5	7-5	7-5	7-5	7-5	7-5	
Time		10:59	9:57	10:12	12:13	12:30	12:40	13:56	14:12	14:22	
Elapsed Time, Hours		151.3	222.2	222.5	224.5	224.8	225.0	226.2	226.5	226.7	
T_0 , °C		1693	1679	—	—	1679	—	—	1678	—	
T_0 Corrected, °C		1699	1685	—	—	1685	—	—	1684	—	
$\Delta T_{\text{Bell Jar}}$, °C		11	11	—	—	11	—	—	11	—	
T_H , °C		1710	1696	—	—	1696	—	—	1695	—	
ΔT_E , °C		23	23	—	—	23	—	—	23	—	
T_E , °K		1960	1946	—	—	1946	—	—	1945	—	
V_0 , volts		0.607	0.601	—	—	0.601	—	—	0.594	—	
I_0 , amps		52.3	52.2	—	—	52.4	—	—	51.9	—	
P_0 , watts											
I-V Trace No.			(1)	(2)	(3)		(4)	(5)		(6)	
T_R	mv	14.9	15.0		8.9	14.8		8.9	14.9		
	°C	364	367		219	362		219	364		
	°K	637	640		482	635		482	637		
T_C	mv	29.4	30.0		1.9	29.9		2.1	29.9		
	°C	706	721		47	718		52	718		
	°K	979	994		320	991		325	991		
T_C base inner	mv				CYCLE #1			CYCLE #2			
	°C										
T_C base outer	mv										
	°C										
T_{Radiator}	mv										
	°C										
V_{eb} , volts		970	970		1040	969		1040	969		
I_{eb} , mA		384.0	378.0		0	378.9		0	380.0		
E_{Filament} , volts		5.1	5.1		0	5.0		0	5.0		
I_{Filament} , amps		23	22		0	22		0	22		
$I_{\text{Coll. Heater}}$, amps		—	—		—	—		—	—		
$I_{\text{Res. Heater}}$, amps		2.19	2.17	2.17	2.17	2.17	2.17	2.17	2.17	2.17	
Vacuum, 10^{-6} mm Hg		2.2	2.0		2.1	2.0		1.9	1.8		
Measured Efficiency, %											

NOTES: (1) END OF 200 HOURS STEADY STATE.
 (2) SHUT OFF EB BOMBARDMENT, CYCLE #1. RESERVOIR HEATER LEFT ON.
 (3) TURNED POWER ON TO FULL BOMBARDMENT $T_0 \rightarrow 1940^\circ\text{C}$
 (4) SHUT OFF, CYCLE #2.
 (5) SAME AS NOTE (3).
 (6) SHUT OFF, CYCLE #3.



Converter No. T/E - 3

Run No. 4

Observer P. Brosen

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		7-5	7-5	7-5	7-6	7-6	7-6	7-6	7-6	7-6	7-14
Time		15:31	15:44	15:54	10:10	10:28	10:33	11:20	11:35	11:43	10:55
Elapsed Time, Hours		227.8	228.0	228.2	246.4	246.8	246.9	247.6	247.9	248.0	439.2
T_0 , °C		—	1691	1688	—	1683	1681	—	1688	1690	1688
T_0 Corrected, °C		—	1697	1694	—	1689	1687	—	1694	1696	1694
$\Delta T_{\text{Bell Jar}}$, °C		—	11	11	—	11	11	—	11	11	11
T_H , °C		—	1708	1705	—	1700	1698	—	1705	1707	1705
ΔT_E , °C		—	23	23	—	23	23	—	23	23	23
T_E , °K		—	1958	1955	—	1950	1948	—	1955	1957	1955
V_0 , volts		—	0.597	0.600	0	0.607	0.609	0	0.596	0.595	0.593
I_0 , amps		—	50.4	50.9	0	51.9	51.9	0	51.0	51.1	50.5
P_0 , watts											
I-V Trace No.		(1)		(2)	(3)		(4)	(5)		(6)	
T_R	mv	8.9	14.9	14.9	9.0	14.9	14.9	2.5	14.9	14.9	14.9
	°C	219	364	364	222	364	364	62	364	364	364
	°K	482	637	637	495	637	637	335	637	637	637
T_C	mv	2.3	29.9	29.9	1.9	29.9	29.9	2.9	29.9	29.9	29.5
	°C	57	718	718	47	718	718	71	718	718	709
	°K	330	991	991	320	991	991	344	991	991	982
T_C base inner	mv	CYCLE #3			CYCLE #4			CYCLE #5			
	°C										
T_C base outer	mv										
	°C										
T_{Radiator}	mv										
	°C										
V_{eb} , volts		1040	969	969	1035	965	965	1035	965	965	964
I_{eb} , mA		0	381.4	381.1	0	378.9	378.7	0	380.2	380.9	381.6
E_{Filament} , volts		0	5.0	5.0	0	5.0	5.0	0	5.0	5.0	5.1
I_{Filament} , amps		0	22	22	0	22	22	0	22	22	22
$I_{\text{Coll. Heater}}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{\text{Res. Heater}}$, amps		2.17	2.16	2.17	2.19	2.20	2.17	2.0	2.17	2.17	2.17
Vacuum, 10^{-6} mm Hg			1.8	1.8	2.2	2.0	2.0	2.1	2.1	2.1	1.9
Measured Efficiency, %											

NOTES: (1) TURNED FULL POWER ON OUTPUT AT END OF 10 MIN: 0.58V 48.9A.
 (2) POWER OFF
 (3) FULL POWER TURNED ON
 (4) POWER OFF, RESERVOIR HEATER OFF
 (5) POWER ON, RESERVOIR ON
 (6) LEFT UNIT TO RUN IN STEADY STATE AT THIS SETTING



Converter No. T/E -3

Run No. 4

Observer P. Brasen

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		7-14	7-14	7-14	7-14	7-14	7-14		7-16	7-16	
Time		13:19	14:32	14:52	15:15	16:50	17:13		16:18	16:42	
Elapsed Time, Hours		441.6	442.8	443.1	443.5	445.1	445.5		492.6	493.0	
T_0 , °C		1683	—	1683	1682	—	1680		—	1678	
T_0 Corrected, °C		1689	—	1689	1688	—	1686		—	1684	
$\Delta T_{\text{Bell Jar}}$, °C		11	—	11	11	—	11		—	11	
T_H , °C		1700	—	1700	1699	—	1697		—	1695	
ΔT_E , °C		23	—	23	23	—	23		—	23	
T_E , °K		1950	—	1950	1949	—	1947		—	1945	
V_0 , volts		0.597	0	0.595	0.601	0	0.600		0	0.602	
I_0 , amps		51.2	0	51.9	52.0	0	51.6		0	52.2	
P_0 , watts											
I-V Trace No.		(1) —	(2)		(3)	(4)		(5)	(6)	(7)	
T_R	mv	14.4	8.2	14.3	14.4	7.8	14.3		R.T.	14.4	
	°C	353	202	350	353	192	350			353	
	°K	626	475	623	626	465	623			626	
T_C	mv	29.5	2.3	29.5	29.6	2.3	29.5		R.T.	29.5	
	°C	709	57	709	711	57	709			709	
	°K	982	330	982	984	330	982			982	
T_C base inner	mv		CYCLE #6			CYCLE #7			CYCLE #8		
	°C										
T_C base outer	mv										
	°C										
T_{Radiator}	mv										
	°C										
V_{eb} , volts		965	1040	965	965	1040	965		1042	964	
I_{eb} , mA		383.0	0	381.3	382.3	0	381.8		0	382.3	
E_{Filament} , volts		5.1	0	5.1	5.1	0	5.1		0	5.1	
I_{Filament} , amps		21	0	21	21	0	21		0	21	
$I_{\text{Coll. Heater}}$, amps		—	—	—	—	—	—		—	—	
$I_{\text{Res. Heater}}$, amps		2.00	2.00	2.01	2.02	2.01	2.02		0	2.02	
Vacuum, 10^{-6} mm Hg		1.8	1.9	1.9	1.9	1.9	1.9		2.0	2.1	
Measured Efficiency, %											

NOTES: (1) OPTIMUM RESERVOIR PRESSURE APPEARS TO HAVE DECREASED.
POWER OFF FOR NEXT CYCLE
(2) POWER ON
(3) POWER OFF
(4) POWER ON T_2 & T_C READ ON RECORDER 32 in/hr chart speed
(5) POWER OFF RES. & CONV.
(6) ALL POWER ON
(7) POWER OFF FOR 35 MIN (DARK PERIOD OF EARTH ORBIT) RESERVOIR ON.



Converter No. T/E -3

Run No. 4 & 5

Observer P. Brosner

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		7-16	7-16	7-17	7-17	7-17	7-17	7-17	7-17	7-18	
Time		17:20	17:40	10:44	11:10	11:55	13:07	14:00	14:32	13:02	
Elapsed Time, Hours		493.6	494.0	511.0	511.3	512.2	513.4	514.3	514.8	516.6	
T _O , °C		—	1676	—	1678	—	1674	—	1674	1684	
T _O Corrected, °C		—	1682	—	1684	—	1680	—	1680	1690	
ΔT _{Bell Jar} , °C		—	11	—	11	—	11	—	11	11	
T _H , °C		—	1693	—	1695	—	1691	—	1691	1701	
ΔT _E , °C		—	23	—	23	—	23	—	23	23	
T _E , °K		—	1943	—	1945	—	1941	—	1941	1951	
V _O , volts		0	0.600	0	0.611	0	0.608	0	0.604	0.600	
I _O , amps		0	51.9	0	51.9	0	51.9	0	51.8	51.9	
P _O , watts											
I-V Trace No.		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)		
T _R	mv	8.5	14.3	1.6	14.3	2.5	14.5	2.4	14.5	14.9	
	°C	209	350	40	350	62	355	59	355	364	
	°K	482	623	313	623	335	628	632	628	637	
T _C	mv	3.4	28.5	1.2	29.5	3.0	29.9	2.9	29.5	29.9	
	°C	83	685	30	709	73	718	71	709	718	
	°K	356	958	303	982	346	991	344	982	991	
T _C base inner	mv	CYCLE #9		CYCLE #10		CYCLE #11		CYCLE #12			
	°C										
T _C base outer	mv										
	°C										
T _{Radiator}	mv										
	°C										
V _{eb} , volts		1042	965	1035	963	1035	963	1035	963	964	
I _{eb} , mA		0	380.4	0	380.1	0	377.9	0	377.3	381.0	
E _{Filament} , volts		0	5.0	0	5.0	0	5.0	0	5.0	5.2	
I _{Filament} , amps		0	21.0	0	20.5	0	20.5	0	20.5	21.0	
I _{Coll. Heater} , amps		—	—	—	—	—	—	—	—	—	
I _{Res. Heater} , amps		2.02	2.02	0	2.01	0	2.01	0	2.01	2.05	
Vacuum, 10 ⁻⁶ mm Hg		2.0	2.1	2.1	2.2	2.0	2.0	2.0	2.0	4.0	
Measured Efficiency, %											

NOTES: (1) POWER ON. RESERVOIR VOLTAGE AT POWER SUPPLY = 0.95 VOLT

(2) ALL POWER OFF.

(3) " " ON.

(4) " " OFF.

(5) " " ON.

(6) " " OFF.

(7) " " ON.

(8) " " OFF.

BELL JAR OPENED TO CORRECT VOLTAGE TAP CONNECTION FROM A TO B. END OF TEST.

